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14. ABSTRACT
This final report discusses researchers working at The University of Texas at Austin whose work has been possible through the Strategic Partnership in Nanotechnology (SPRING) grant. These researchers have either received support directly from awarded funds or used equipment purchased through this grant. The research can be broken into two research areas "Nanotechnology for Energy Needs" and "Nanoelectronics". Highlights of both projects are outlines below. The SPRING award also made a large number of instrument purchases possible. Much of this equipment is housed in the SPRING/KECK clean room facility which is an open facility serving the University of Texas at Austin.

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Final Report for "Strategic Partnership for Research in Nanotechnology"
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Grant Number: FA9550-04-1-0331
Principal Investigator: Paul Barbara
Institution: The University of Texas at Austin

This final report covers a number of researchers working at The University of Texas at Austin whose work has been possible through the Strategic Partnership in Nanotechnology (SPRING) grant. These researchers have either received support directly from awarded funds or used equipment purchased through this grant. The research can be broken into two research areas "Nanotechnology for Energy Needs" and "Nanoelectronics". Highlights of both projects are outlined below.

1. Nanotechnology for Energy Needs

Developing new methods to meet the world's ever increasing energy demands will require radical solutions that nanoscience and nanotechnology have the potential to address. The CNM faculty members are tackling these new problems in two major areas of renewable energy research photovoltaics and hydrogen fuel cells. The CNM efforts couple both basic science and engineering to develop new materials, understanding, and devices.

An excellent example of our approach is the research of Dr. **Paul Barbara** (Chemistry and Biochemistry) whose research lab has developed powerful single molecule spectroscopy tools to characterize individual conjugated polymers. [Barbara, 2005][Palacios, 2006] We support fundamental research on photovoltaics including work electrochem studies of organics, single molecule spectroscopy of organic materials in a device environment, and nanoparticle synthetic research. This method involves simultaneous single molecule fluorescence spectroscopy while controlling oxidation/reduction of individual molecules or nanoparticles in an electronic device. The technique, which is denoted by *F-V*/SMS (where "*F*" signifies fluorescence intensity), is analogous in several ways to current vs. voltage (*I-V*) measurements for devices and electrochemical cells. For example, *F-V*/SMS data at different sweep rates can be analyzed to obtain information on both energetics and kinetics of charge transfer (oxidation/reduction) processes involving the single molecules. This approach is particularly useful for studying the interactions between excitons and polarons. This is achieved by recording the single molecule fluorescence intensity as a function of device bias, which controls the population of polarons. This method also offers a unique means for characterizing the chemical nature of the poorly understood photochemically induced intermediate states of conjugated polymers that are responsible for fluorescence "blinking" and "flickering", i.e. intermittency. By studying the bias dependence of the SMS during the lifetime of the fluorescence "flickering" intermediate, information on the *oxidation/reduction properties* (e.g HOMO energies) of the intermediate can be determined. In particular, Park *et al* have applied the technique to elucidate the chemical nature of photo-oxidation intermediates causing photo-bleaching of MEH-PPV in an electronic device structure.

Also working in the area of fundamental photovoltaics is **David Vanden Bout's** (Chemistry and Biochemistry) group. They are utilizing high-resolution optical microscopy techniques that are capable of mapping out fluorescence lifetimes on the nanoscale to probe charge separation in conjugated polymer thin films. [Bunz, 2005] This initial charge separation is critical to the success of any photovoltaic device. Also, crucial to the advancement of photovoltaic research are new materials. In particular, hybrid photovoltaics comprised of both organics and inorganics rely on high quality monodisperse nanoparticles. **Keith Stevenson's** (Chemistry and Biochemistry) group is working on characterization of charge transport behavior in organic and metal oxide thin films. This project focuses on the development of high resolution optical
and scanning probe microscopy tools for evaluation of charge transport in heterogeneous, nanostructured materials. [McEvoy, 20006] Spatially resolved measurements obtained at nanoscopic length scales aids in the understanding of structure-property and materials performance
relationships crucial for the development of next-generation batteries, fuel cells, and solar cells.

Brian Korgel's (Chemical Engineering) research group has developed a number of synthetic methods for the production of bulk quantities of high quality semiconductor nanowires with very low dispersion in size. [Lu, 2005] [Smith, 2006] These nanowires have a number of applications ranging from photovoltaics to low-energy emissive displays. Finally, low cost, flexible plastic photovoltaics will require new manufacturing technology coupled with new plastic electronics. Dr. **Lynn Loo** (Chemical Engineering) is leading this effort in the CNM with the development of solution processible organic and polymer conductors and semiconductors for a variety of applications. [Dickey, 2006]

Another area where nanoscience and technology have the potential to make big impacts in renewable energy is in the development of fuel cell technology. **Allen Bard's** (Chemistry and Biochemistry) research group has been working on mixed metal nanoparticle catalysts for oxygen reduction, a key step in proton exchange membrane fuel cells. They have developed a rapid screening method for testing electrocatlysis of nanoparticle arrays utilizing scanning electrochemical microscopy. These efforts have lead to the discovery of several non-Pt materials with activities on par with standard Pt catalysts. [Walsh, 2006]

Nanoscale catalysts have shown promising properties for a number of critical applications related to renewable energy and green chemical synthesis, because of their high surface to volume ratio and the ability to produce nanoparticles of a wide variety of sizes and shape. The laboratory of **Richard Crooks** (Chemistry and Biochemistry) has developed a new method for the synthesis of monodisperse dendrimer-encapsulated metal nanoparticles with well-defined stoichiometry. These protected nanoparticles can be made from nearly any metal, but when made from platinum and palladium serve as highly selective catalysts. [Wilson, 2006] The group has recently demonstrated the effect of size and face selectivity for Pd Nanoparticles.

2. Nanoelectronics

A key emerging area in nanotechnology is nanoelectronics. The CNM has developed a working partnership with the Microelectronics Research Center (MRC) at the University of Texas' Pickle Campus to jointly push forward the development of nanoscale electronics. These efforts include both fundamental research on materials as well as applied engineering and testing of new nanoscale devices.

One area of Nanoelectronics research is "quantum engineering" of metallic and magnetic structures. **Ken Shih** (Physics) investigates how quantum confinement of electronic states impacts the thermodynamic properties of metallic nanostructures and how such confinement influences the collective bulk electronic properties such as magnetism and superconductivity. [Jiang, 2004] [Eom, 2006]

Another area of research in the Shih lab is "quantum coherent control" of photonic properties of semiconductor nanostructures. Exploration of new possibilities to control the quantum optical properties of such nanostructures and to harness these quantum optical properties for novel optical device applications is underway in the lab. These studies are providing the basic fundamental knowledge necessary for fabrication of a quantum computing device and quantum information technology. [Wang, 2005]

Ray Chen (Electrical and Computer Engineering) recently invented an ultra-compact silicon-photonic-crystal electro-optic modulator silicon modulator fabricated by standard lithographic techniques. This photonic crystal slows the speed of light down sufficiently that the intensity can be modulated by a very small electric current. [Jiang, 2005] This design requires ten times less power consumption normally needed for silicon modulators. Once these modulators can be combined with semiconductor lasers on a silicon platform they will significantly increase interconnect speeds and efficiencies.

Li Shi (Mechanical Engineering) is creating nanowires of thermoelectric materials (materials capable of converting voltage differences into heat and vice versa). Based on theoretical calculations these nearly one-dimensional structures should have exceptional thermoelectric properties. After synthesis of a batch of nanowires, individual nanostructures are placed onto a micron-sized thermal test bed structure that was developed and fabricated in Shi's laboratory. Once fastened to the MEMS heater with a small amount of platinum 'glue', the electrical and thermal properties of individual nanowires can be measured. [Zhou, 2005] [Shi, 2005]

The CNM efforts in nanoelectronics efforts are also branching out from traditional semiconductors and into emerging areas such as spintronics. **Maxim Tsoi's** (Physics) research is focused on this new technological discipline that refers to studying the role played by an electron spin in solid-state physics. The main focus of his work is in current driven spin-transfer phenomena. [Beach, 2005] His research group has recently demonstrated transfer of spin-angular momentum across and interface between ferromagnetic and anti-ferromagnetic metals. The spin transfer is mediated by an electrical current and revealed by variation in the exchange bias at the ferromagnet/antiferromagnet interface. [Wei, 2006] Current-mediated variation of exchange bias can be used to control the magnetic state of spin-valve devices, e.g., in magnetic memory applications which create an entirely new class of high-density non volatile memory.

3. Instrument Purchases

The SPRING at UT-Austin allowed Paul Barbara and co-workers to add several key components to the SPRING/KECK clean room on campus. The SPRING/KECK facility is now set up for optical lithography, additive and subtractive growth/etch facilities, device packaging (critical point drier, wire bonder, and dicing saw) and characterization (profilometry, spectroscopic ellipsometry, and digital microscopy). In fall of 2006 the SPRING/KECK facility will move into the brand new state-of-the-art Nano Science and Technology (NST) building on campus. An entire floor of the NST building is comprised of a 3500 square foot hard-wall clean room, split into Class 100 and Class 1000 areas. The new clean room has been designed with integral plumbing and sensing for a variety of toxic etch and growth gasses allowing for acquisition of more etch and growth tools. We will also add electron-beam lithography to fabricate devices with critical dimensions approaching 25 nm.

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